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SUMMARY

A survey of the operations of three different prototype light observation helicopters and of two large load-lifting helicopters, each involved in simulated military operations, was conducted with helicopter flight recorders in order to provide a basis for extending helicopter design and service life criteria. The data are representative of 3064 flights (2870 flying hours) for the light helicopters and 149 flights (125 flying hours) for the load lifters. The operating experiences are presented in terms of the time spent within different airspeed brackets, the classifiable flight conditions of climb, en route, and descent, and at different rotor rotational speeds. Normal acceleration occurrences above the incremental value of ±0.4g are also presented.

Results for this survey show that each helicopter spent a large amount of time in the upper portion of the speed range and exceeded its handbook maximum velocity for a small percentage of the total flight time. Broad variations in rates of climb and descent occurred over a wide range of airspeeds. Normal acceleration experiences reached 75 to 98 percent of the aerodynamically attainable maximum estimated for the specific flight conditions. Rotor rotational speeds were held at the normal values for most of the flight time, but a large number of values exceeded either the upper or lower red-line limits.

INTRODUCTION

Surveys of various helicopter operating experiences can enable the designer to furnish the user with a better performing aircraft, and one which is more suitable to his needs. The National Aeronautics and Space Administration has made a continuing effort to provide this information as a means of assessing the adequacy of design and service life criteria. (See refs. 1 to 4.) The development of more modern helicopters and changes in operating procedures has made possible a wider variety of helicopter applications and new variations in flight profiles, and thus has created a need for additional flight surveys.

The purpose of this paper is to extend the information on the utilization of helicopters, particularly when involved in newer missions. The flight operations surveyed were those involving three light helicopter prototypes of different design at Fort Rucker, Alabama, and two identical large load lifters at Fort Benning, Georgia. The small helicopters surveyed at Fort Rucker were of the light observation class. These helicopters were involved in a prototype evaluation while engaged in simulated military operations. Each vehicle flew a specified number of profiles which were intended to be representative of their anticipated service usage. The larger helicopters were primarily involved in load-lifting tasks, typical of combat support missions. The tasks involved both internal and external cargo transfers. The data from these surveys are presented in the form of bar graphs, time spent in various operational categories, and probability curves. Comparisons with previous results were made whenever possible.

HELICOPTER OPERATIONS

The three light observation helicopters, all single rotor and turbine powered, were operated in the vicinity of Fort Rucker, Alabama, under simulated military missions. These vehicles ranged from 2100 to 2570 pounds gross weight and were the first light turbine helicopters to be surveyed by the NASA. This survey was conducted over a period of 6 months during which time a total of 3064 flights, representing approximately 2870 combined flight hours, were recorded. A flight was considered to be the time elapsed from engine start to stop and may include more than one landing.

The two load-lifting military helicopters were twin-turbine transports of about 38 000 pounds gross weight and were also the first of their type to be surveyed by NASA. These vehicles were operated at Fort Benning, Georgia, and their missions were essentially composed of load-lifting and transport tasks. The records of 149 flights, representing approximately 125 flying hours, were obtained from two identical vehicles during a 5-month period.

INSTRUMENTATION AND DATA ANALYSIS

NASA helicopter flight recorders were used to obtain the data for these surveys. This instrumentation records time histories of airspeed, center-of-gravity normal acceleration, pressure altitude, and rotor rotational speed (VGHN information). These recorders are the same type of recording packages used during previous operational surveys of helicopters and described in reference 4.

The complete analysis for both types of helicopters consisted of a visual editing of all the records for the rotor rotational speed data and for unusual occurrences. Also, for the load lifters only, all the records were read in obtaining the normal-acceleration data. The compilation of the remaining measured parameters was based on a sampling of 25 percent of the recorded data. (For somewhat simpler operations in the past, a 10-percent sampling of the records was sufficient.) The results are presented separately for each of the light observation helicopters and are presented combined for the load lifters. In addition, the results presented in this report are compared with those of previous studies whenever possible.

The flight conditions were classified as follows: time spent in various airspeed brackets, time spent in climb and descent, landing occurrences, normal acceleration occurrences, and rotor rotational speed experiences. Part of a time history is shown in figure 1, from which the flight conditions of climb, en route, and descent are clearly identifiable. The helicopters were considered to be climbing or descending when the rate of change in altitude was greater than ±300 feet per minute, the rates being read to the nearest 100 feet per minute.

RESULTS AND DISCUSSION

The operating experiences are presented according to the time spent within classifiable flight conditions for each of the military vehicles. A summary of the flight profiles of the five helicopters surveyed for this report is presented in table I. For comparison purposes, a similar summary of the data from reference 4 is also included in table I.

For the lighter helicopters, the time in climb ranged from 9 to 10 percent, time en route ranged from 77 to 78 percent, and time in descent ranged from 12 to 13 percent. In distinction to the previous work cited in table I, these distributions are narrower. Also, such results strongly indicate that all the lighter vehicles were handled similarly. The load lifters spent a slightly larger percentage of time in both climb and descent than the lighter vehicles did.

Operating Airspeed

The percentage of time spent at different airspeeds for the vehicles surveyed is presented in figure 2(a). This figure shows the percentage of total time within airspeed increments plotted against the indicated airspeed. The airspeed is subdivided into incremental categories of 20 knots except for the first range which is measured from 0 to 40 knots. This subdivision is made because past experience has shown that the airspeed sensor is inaccurate from 0 to 20 knots and would consequently yield doubtful results. The airspeed is also presented in terms of percentage of maximum design airspeed V_{max} for each helicopter. The V_{max} values for the light helicopters (A, B, and C) and the load lifters are 115, 110, 128, and 130 knots, respectively, as obtained from the pilot handbooks.

Figure 2(a) indicates that the vehicles were operated near or above their maximum velocity for a small percentage of the flight time. Operating very near or above V_{max} is often indicative of high vibratory torsional and bending moments acting on the blade, particularly if blade stall is encountered. (See ref. 5.) The shapes of the airspeed distributions of the three light observation helicopters were similar to those obtained during past surveys. The largest percentage of total time was spent in the range of 70 to 90 percent of V_{max}, which was slightly higher than that obtained in previous studies. On the other hand, the load lifters spent large percentages of time in two airspeed brackets, namely, the lowest airspeed bracket and the one comparable with the lighter vehicles. The higher percentage in the 0- to 40-knot range is compatible with the load lifter's task which exposed them to more hover and low-speed time while receiving and delivering loads.

Another important aspect for the helicopter designer is the significance of the 0- to 40-knot range. As pointed out in reference 6, vibratory moments during transition and landing approach become very large; such low-speed stress conditions can be as critical as high-speed stresses. The lighter vehicles were operated in this low-speed bracket for about 10 to 12 percent of the total flight time. These values, for the most part, represent a reduction in the time spent in this range as compared with those of reference 4. The load lifters, by contrast, spent about 28 percent of their total flight time in this low-speed bracket.

Operating Rates of Climb and Descent

The airspeed experiences for the vehicles surveyed are subdivided in figure 2(b), according to their occurrences within the three flight conditions of climb, en route, and descent. Since climbs and descents are generally associated with maneuver flight and the likelihood of encountering higher blade stress levels is enhanced during maneuvering, the climb and descent portions have been separated as indicated. In addition, the en route flight condition separation can allow proper weighting of the time that the rotor blades are subjected to the low-to-moderate periodic bending moments which may occur for a large number of cycles.

Percentages of time spent within different rates of climb and descent are presented in figures 3 and 4, respectively. The percentages in figure 3 are based on the total time spent in climb and in figure 4, are based on the total time spent in descent. In each figure, they are separated with regard to airspeed brackets.

The distribution of the rates of climb for each vehicle is presented in figure 3. The rates most utilized by the light helicopters occurred below 800 feet per minute, the larger percentage being noted within the 40- to 60-knot airspeed bracket. The load lifters experienced a prevalence of the same climb rates but at slightly higher airspeeds. The trends in the climb-rate distribution do not have as many pronounced peaks as do those presented in past surveys, and indicate a lesser preference for any specific climb rate.

The rates of descent, presented for each vehicle in figure 4, show a larger concentration at the lower rates within all of the airspeed ranges than do those of reference 4. The light helicopters spent most of their descent time at 300 to 400 feet per minute whereas the rates for the load lifters showed a nearly even distribution over the range of 300 to 700 feet per minute. Generally, the rates of descent for the light helicopters appear different from those reported in references 3 and 4 in that rates presented herein were not as evenly distributed.

Summary plots for these flight conditions provide further insight as to the time distribution of the rates of climb and descent and are shown in figure 5. As a probability-type curve, this figure indicates the percentage of total flight time surveyed that the vehicles exceeded a specific rate of climb or descent. For each of the vehicles, only about 1 to 4 percent of the total flight time was spent above a climb rate of 1000 feet per minute. This result represents a reduction in the time spent at the higher climb rates, as compared with previous results, and thus reduces one source of high blade stresses. For the lighter vehicles, most of the descent time (about 8 percent of the total flight time) was spent at rates of 600 feet per minute or less. The time spent at these moderate descent rates, insofar as they occur at low speeds, can also produce very high blade stresses.

Landing Occurrences

The number of landings per hour may be important to the designer for each represents a transition, a flare, and a ground impact. During this survey, each light observation helicopter made approximately 3900 landings in about 950 flight hours. Specifically, helicopter A averaged 4.1 landings per hour, helicopter B averaged 4.7 landings per hour, and helicopter C averaged 4.3 landings per hour. The load lifters experienced 2.1 landings per hour as a result of the 267 landings in 125 hours of flight data. These numbers are comparable with the values obtained for similar vehicles in previous surveys.

Normal-Acceleration Occurrences

Normal accelerations experienced by the five vehicles were analyzed by the sampling technique reported in references 3 and 4. The sampling technique provides results that are representative of the total distribution, and for this survey, no unusual trends in the acceleration traces were noted.

The distribution of normal-acceleration increments which exceed ±0.4g are given in table II and are separated according to the flight conditions of climb, en route, and descent, for comparison with results published in reference 4. The number of accelerations per hour in excess of ±0.4g without respect to magnitude or flight condition were 3.2 for helicopter A, 2.0 for helicopter B, 4.0 for helicopter C, and 1.0 for the load lifters. The number of acceleration exceedances per hour were comparable with those reported for the military and mountain-based operations (1.85 to 5.45 exceedances per hour) in reference 4, although greater than that reported for the airmail operation (0.37 exceedances per hour) in reference 3.

Based on the data in table II, the frequency of occurrences of normal accelerations encountered by each of the vehicles is presented in figure 6. This figure shows the number of both positive and negative acceleration peaks expected to reach or exceed a specified increment during each 1000 hours of flight. The data from this survey are compared with the acceleration results for similar operations of past surveys. The acceleration probability curves from the mountain operations of reference 4 are included in figures 6(a), 6(b), and 6(c). The average of the acceleration curves from the airmail survey of reference 3, and the surveys of references 7 and 8 are presented in figure 6(d). The average of the data from references 3, 7, and 8 (transport surveys) are presented for clarity since each of the slopes is nearly the same. As noted, the curves for the three light helicopters compare favorably with reference 4, particularly that of helicopter C. For the remaining two helicopters, a slight downward shift in the curves is apparent, and thus indicates a lower probability of encountering higher accelerations.

The positive acceleration curve for the load lifters agrees with the average transport curve, but it should be noted that the apparent high frequency of occurrence beyond an incremental "g" of 0.8 is probably due to the limited amount of data from this comparatively short survey. The slope of the negative acceleration curve of the load lifters also agrees with the corresponding average curve for the transports, but again a downward shift in the curve is indicated.

Comparing the results of the lighter helicopters with those of the load lifters (in general, the transports) shows that the curves for the lighter vehicles fall above those for the load lifter. This result is to be expected, since the assigned task of the larger transports required less maneuvering than the tasks assigned to the lighter vehicles.

Based on a visual editing of all the flight records, the highest values of normal acceleration for each of the vehicles were as follows:

Vehicle	Normal acceleration, g
Light helicopter A	2.4
Light helicopter B	2.2
Light helicopter C	2.5
Load lifters	2.1

The use of reference 9 permitted the estimation of the aerodynamically maximum attainable normal acceleration for comparison with the maximum values actually achieved during flight. Table III presents several of the high "g" flight conditions for each vehicle along with the corresponding value obtained by use of reference 9. The percentage of the estimated "g" value achieved during each condition is also noted. In making these calculations, the single value of 1.2 was used for the blade section maximum lift coefficient $c_{l_{max}}$ for each vehicle. This approximation was made because of the reasonably similar sections of the blades concerned, and the lack of detailed airfoil section data.

Rotor Rotational Speed

In figure 7 the percentage of total time spent at the various rotational speeds is plotted against the percentage of normal rotor speed. This figure shows that each of the vehicles was operated near 100 percent rotor speed for most of the flight time. Specifically, the rotor speed stayed between 95 to 105 percent for over 95 percent of the total flight time.

The most widespread variation in rotor speed occurred during the descent or autorotative part of the flight profile. This part included experiences which occurred outside the manufacturers' recommended operating limits. Separate indications of the rotor speed excursions outside the red-line (placard) values were tabulated for each vehicle, as shown in table IV. For the most part these excursions were noted as spikes on the rotor speed trace.

The upper placard limit is set at 95 percent of either the design maximum or the demonstrated value, whichever is the lower. For the low-speed end, the red line is set at 105 percent of the larger of the corresponding values. The allowable ranges above 100 percent for the light helicopters are particularly narrow and it would appear that the pilot would have difficulty in controlling these values during the non-governor-regulated power-off conditions. This difficulty may be the reason for the large number of exceedances of the upper red-line values.

Overspeeds and underspeeds become significant depending in part upon the level of normal acceleration at which they occur. Combinations that may be detrimental essentially for a rigid or teetering rotor include: (1) overspeeds occurring at low "g," or (2) underspeeds occurring at high "g." In either case, the "g" level would aggravate the blade bending rather than relieve it. For each of the vehicles surveyed, no such combination of rotor speed and normal acceleration occurred. Additional significance can be placed upon the rotor speeds if the overspeed or underspeed should fall outside a placard band that was based on a design limit. In this event, the rotor systems or blades would have a greater chance of being seriously affected, with the possibility of a failure occurring. However, the placard values are generally based on demonstrated values which, for the high rotor speed case, are notably lower than the design limits.

CONCLUDING REMARKS

Flight profiles have been acquired from three light helicopters engaged in simulated combat operations during their prototype evaluation, and from two large load-lifting helicopters supporting simulated military tactical missions.

The results show that each of the helicopters was operated above the maximum design airspeed for only a very small part of the survey. The airspeed range corresponding to 70 to 90 percent of maximum velocity comprised a large percentage of operating time for all the vehicles. In addition to spending a large percentage in the high-speed bracket, the load lifters showed a nearly equal percentage of time in the lowest airspeed bracket.

The rates of climb and descent were varied and distributed over the entire speed range although the light observation helicopters experienced longer periods at lower rates. The number of landings per flying hour for the light helicopters ranged from 4.1 to 4.7, whereas the load lifters averaged 2.1 landings per hour. These results are comparable with past surveys of similar operations.

The results also indicate that the center-of-gravity normal accelerations above a threshold of ± 0.4g experienced by the light helicopters were comparable with those experienced by military helicopters in previous studies. The number of accelerations per hour in excess of ± 0.4g, regardless of magnitude or flight condition, ranged from 2.0 to 4.0. The number for the load lifters was lower (1.0 exceedance per hour). For each of the operations, the simplified method for estimating the maximum aerodynamically attainable normal acceleration gave values fairly close to those actually utilized.

Rotor-rotational-speed time histories showed that all the vehicles were operated at the normal rotor speeds, within 95 to 105 percent of rotor speed for over 95 percent of the total flight time. Excursions from the normal rotor speed occurred during autorotations, during which time a large number of brief red-line exceedances were recorded.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., March 6, 1967,
721-02-00-07-23.

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TABLE I.- SUMMARY OF FLIGHT PROFILES

Type	Operation	Percentage			Source
		Climb	En route	Descent	
Helicopter A – 2570 lb (1167 kg) turbine single rotor	Military utilization	10	78	12	Present survey
Helicopter B – 2500 lb (1135 kg) turbine single rotor	Military utilization	10	77	13	Present survey
Helicopter C – 2100 lb (953 kg) turbine single rotor	Military utilization	9	78	13	Present survey
Load lifter – 38 000 lb (17 252 kg) twin turbine engine single rotor	Load lifting	11	74	15	Present survey
5500 lb (2497 kg) turbine single rotor	Military utilization	18.8	59.4	21.8	Reference 4
12 000 lb (5448 kg) single rotor	Instrument flight rules training	12.5	75.9	11.6	Reference 4
30 000 lb (13 620 kg) twin-engine single rotor	Load lifting	16	66.6	17.4	Reference 4
2300 lb (1044 kg) single rotor	High altitude	12.2	75.9	11.9	Reference 4

TABLE II.- NORMAL ACCELERATIONS INCLUDING ALL INCREMENTS ABOVE A THRESHOLD OF ±0.4g FOR EACH OF THE HELICOPTERS SURVEYED

Acceleration increments, Δa_n, g units	Number of accelerations experienced by –											
	Light helicopter A			Light helicopter B			Light helicopter C			Load lifters		
	Climb	En route	Descent	Climb	En route	Descent	Climb	En route	Descent	Climb	En route	Descent
0.40	1	146	34	4	23	4	7	110	30	4	6	2
.45	2	38	6	3	25	19		36	4		3	3
.50	2	90	25	2	8	6	4	108	9		4	1
.55	1	3	4		1	2	1	2				
.60	2	48	12	2	7	12		55	11			
.65		1	2		2	1		1				
.70	1	10	5		1	4		23	5			
.75								1				
.80		6	5		2			17	4			
.85								1				
.90								2	4	2	1	
.95												
1.00		2			1							
1.10		2						1			2	
1.20	1				1			1				
1.30								2				
1.40		1						1				
1.50								1				
Total	10	347	93	11	71	48	12	362	67	6	16	7
-0.40	2	46	17	5	42	11	3	72	31	2	10	2
-.45		9	7	1	73	15	1	44	6		3	
-.50	2	22	17	2	19	5		73	17		2	
-.55		4	1			1		2	1		1	
-.60	1	11	10		10	3		33	23	1	2	
-.65		2	1		2							
-.70			2					6	5			
-.75												
-.80			1			2		1	4			
-.85									1			
-.90								1	2			
-.95												
-1.00									1			
Total	5	94	56	8	146	37	4	232	91	3	18	2
	Flight hours surveyed, per condition											
	18.2	150.0	22.6	16.6	126.0	21.0	17.3	149.7	23.9	4.8	31.5	6.2

TABLE III.- COMPARISON OF NORMAL ACCELERATION TO AERODYNAMIC MAXIMUM ESTIMATED FOR SPECIFIC FLIGHT CONDITIONS BY USE OF REFERENCE 7

Aircraft	Normal acceleration, g	Velocity, knots	Altitude		Rotor speed, percent	Mean lift coefficient (achieved)	Calculated acceleration, g	Percent attained
			ft	m				
Helicopter A	2.4	80	500	152	102	0.96	3.00	80
Helicopter A	2.1	60	200	61	102	.91	2.75	76
Helicopter B	2.0	80	100	30.5	103	1.07	2.25	89
Helicopter B	2.2	60	100	30.5	108	1.10	2.40	92
Helicopter C	2.3	110	800	244	102	1.04	2.65	87
Helicopter C	2.5	83	200	61	102	1.17	2.55	98
Load lifter	1.9	80	400	122	100	1.03	2.20	86
Load lifter	2.1	20	200	61	100	1.17	2.15	98

TABLE IV.- NUMBER OF ROTOR SPEED PEAKS OCCURRING OUTSIDE THE RED-LINE LIMITS

Rotor speed percentage	Number of rotor speed peaks for –			
	Helicopter A	Helicopter B	Helicopter C	Load lifters
115 to 116	2	0	2	0
114 to 115	1	0	1	0
113 to 114	0	3	10	0
112 to 113	4	7	16	0
111 to 112	7	9	7	3
110 to 111	18	9	16	0
109 to 110	40	25	59	1
108 to 109	74	32	[c]	0
107 to 108	147	85		1
106 to 107	[a]	131		1
105 to 106		[b]		[d]
104 to 105				
103 to 104				
102 to 103				
101 to 102				
100 to 101				
99 to 100				
98 to 99				
97 to 98				
96 to 97				70
95 to 96				37
94 to 95	23			12
93 to 94	19			1
92 to 93	6			5
91 to 92	3			7
90 to 91	4			0
89 to 90	2			0
88 to 89	3			0
87 to 88	5			0
86 to 87	0			0
85 to 86	2			0
84 to 85	2		0	0
83 to 84	0		0	0
82 to 83	1		0	0
81 to 82	0		2	0
80 to 81	0		1	0
79 to 80	0		1	0
78 to 79	0	0	0	0
77 to 78	0	0	0	0
76 to 77	0	0	1	0
75 to 76	0	0	1	0
74 to 75	0	0	2	0

[a]Red-line limits are for 95- and 107-percent rotor speed (total operation consisted of 982 flight hours).
[b]Red-line limits are for 80- and 106-percent rotor speed (total operation consisted of 907 flight hours).
[c]Red-line limits are for 85- and 109-percent rotor speed (total operation consisted of 981 flight hours).
[d]Red-line limits are for 97- and 111-percent rotor speed (total operation consisted of 125 flight hours).

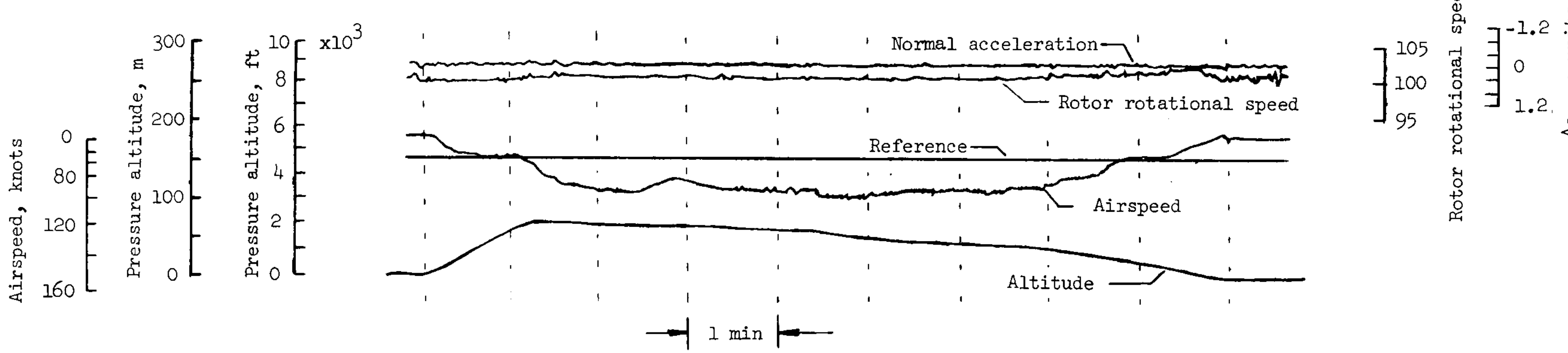
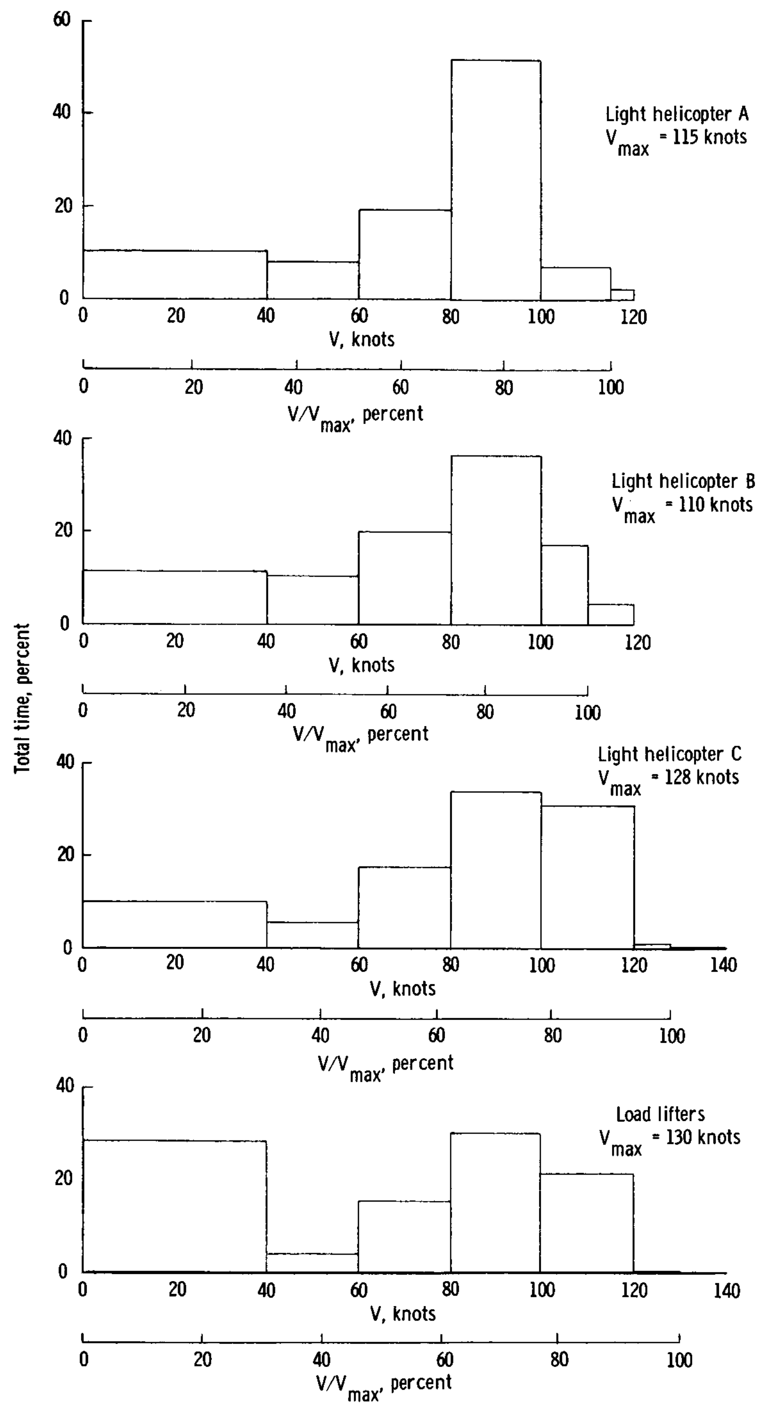
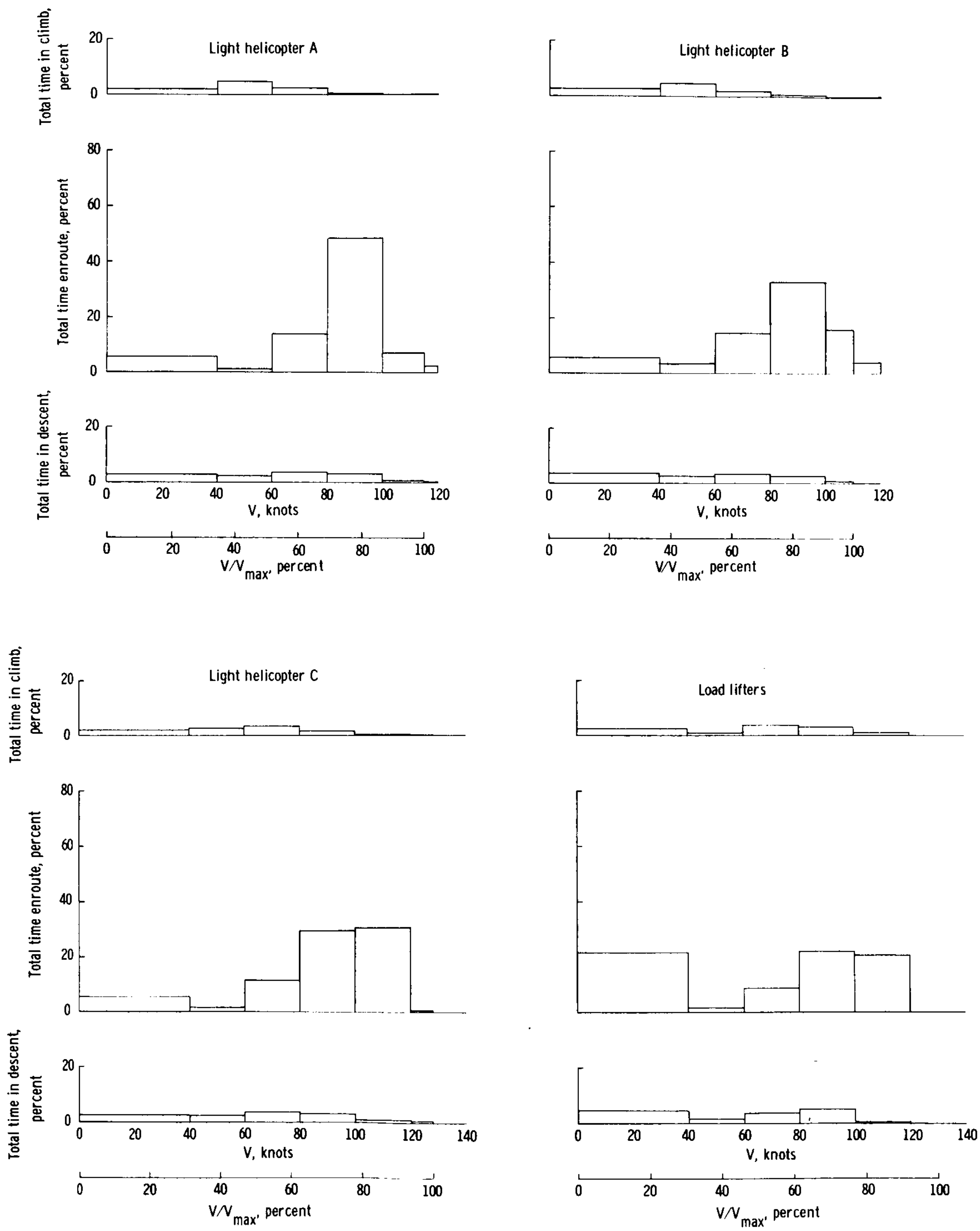


Figure 1.- Sample portion of a flight profile time history from a light observation helicopter.



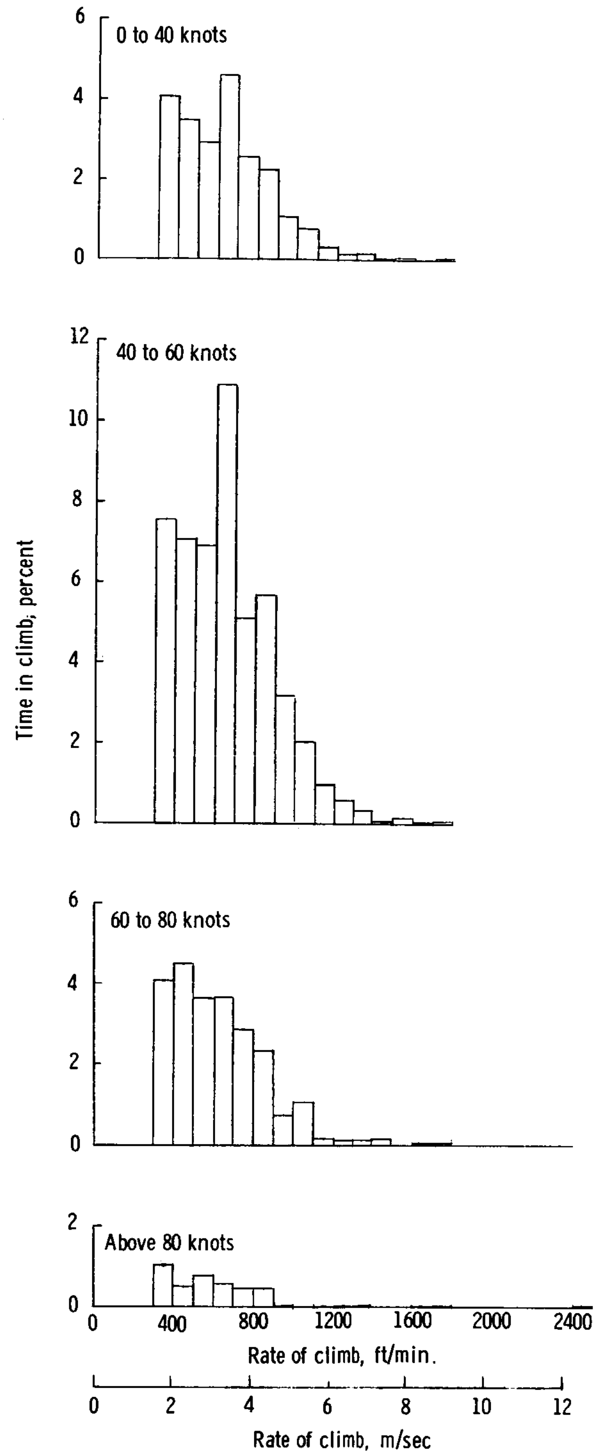
(a) Total mission.

Figure 2.- Operating airspeed V experienced by the helicopters surveyed. (Maximum velocity V_{max} noted from pilot handbook.)



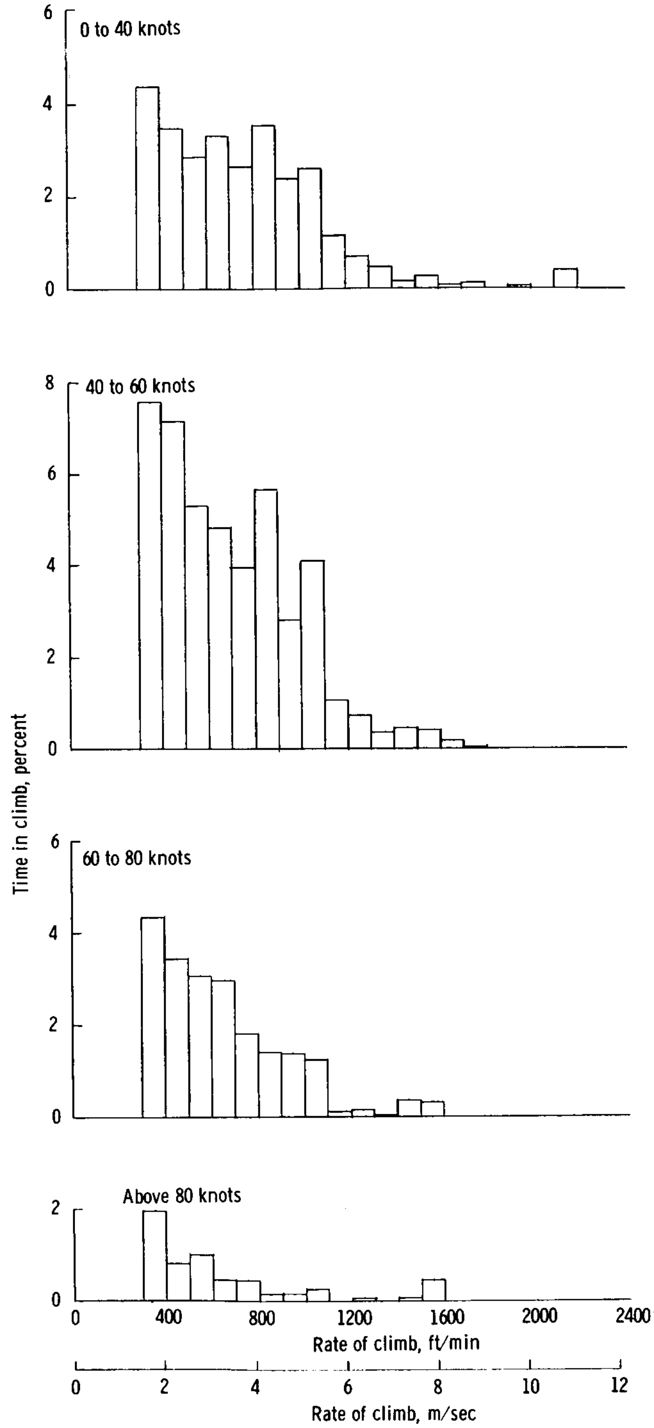
(b) Airspeed according to flight conditions of climb, en route, and descent.

Figure 2.- Concluded.



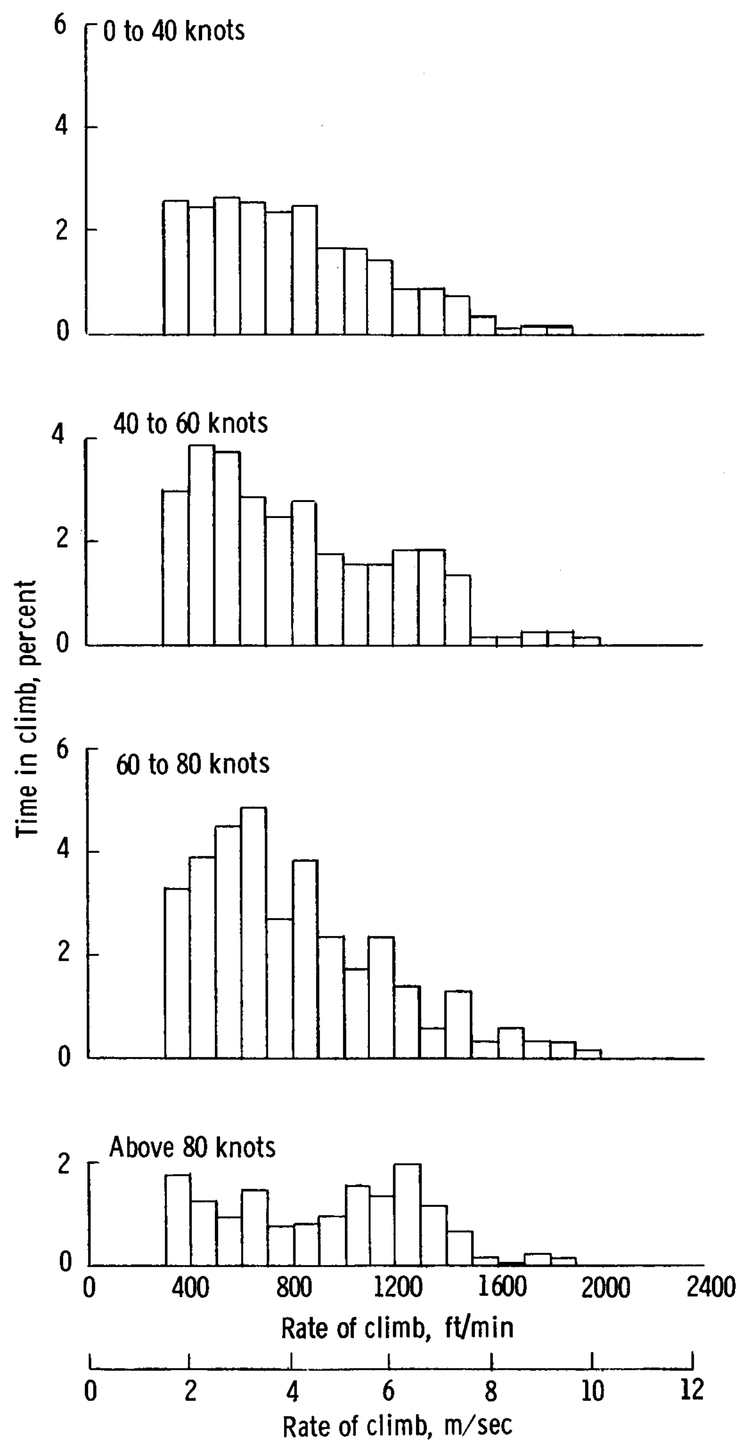
(a) Light helicopter A.

Figure 3.- Operating rates of climb within each speed bracket for each vehicle.



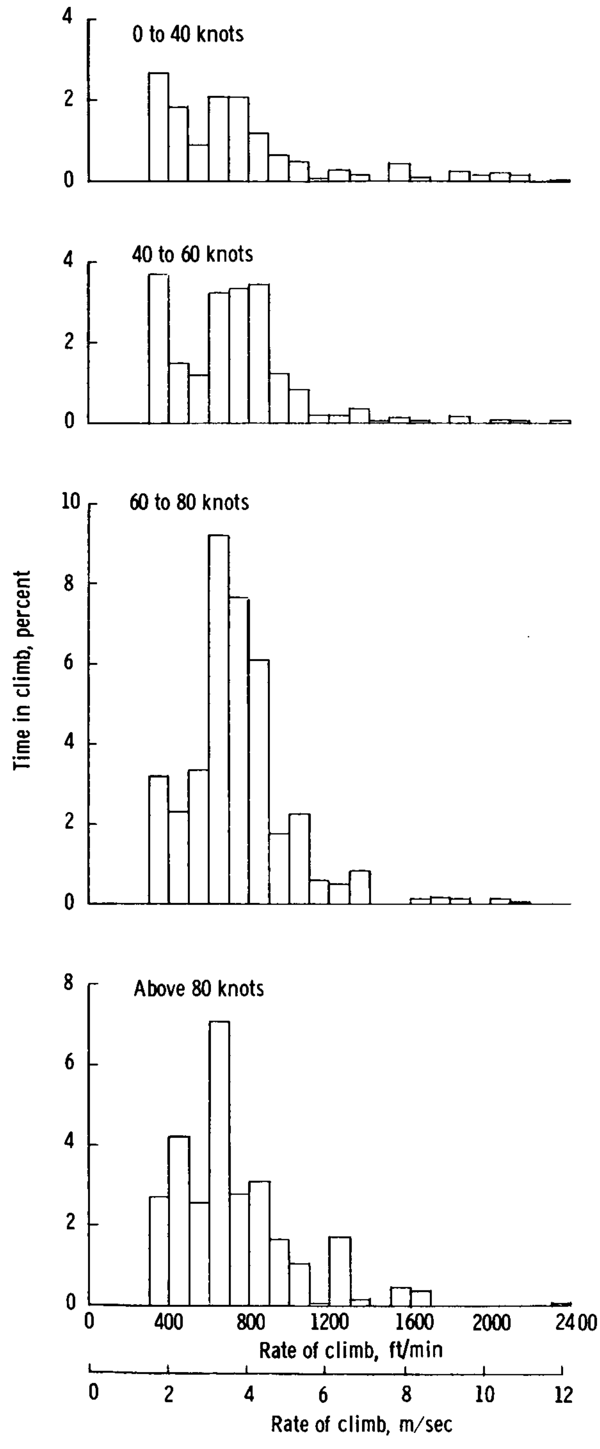
(b) Light helicopter B.

Figure 3.- Continued.



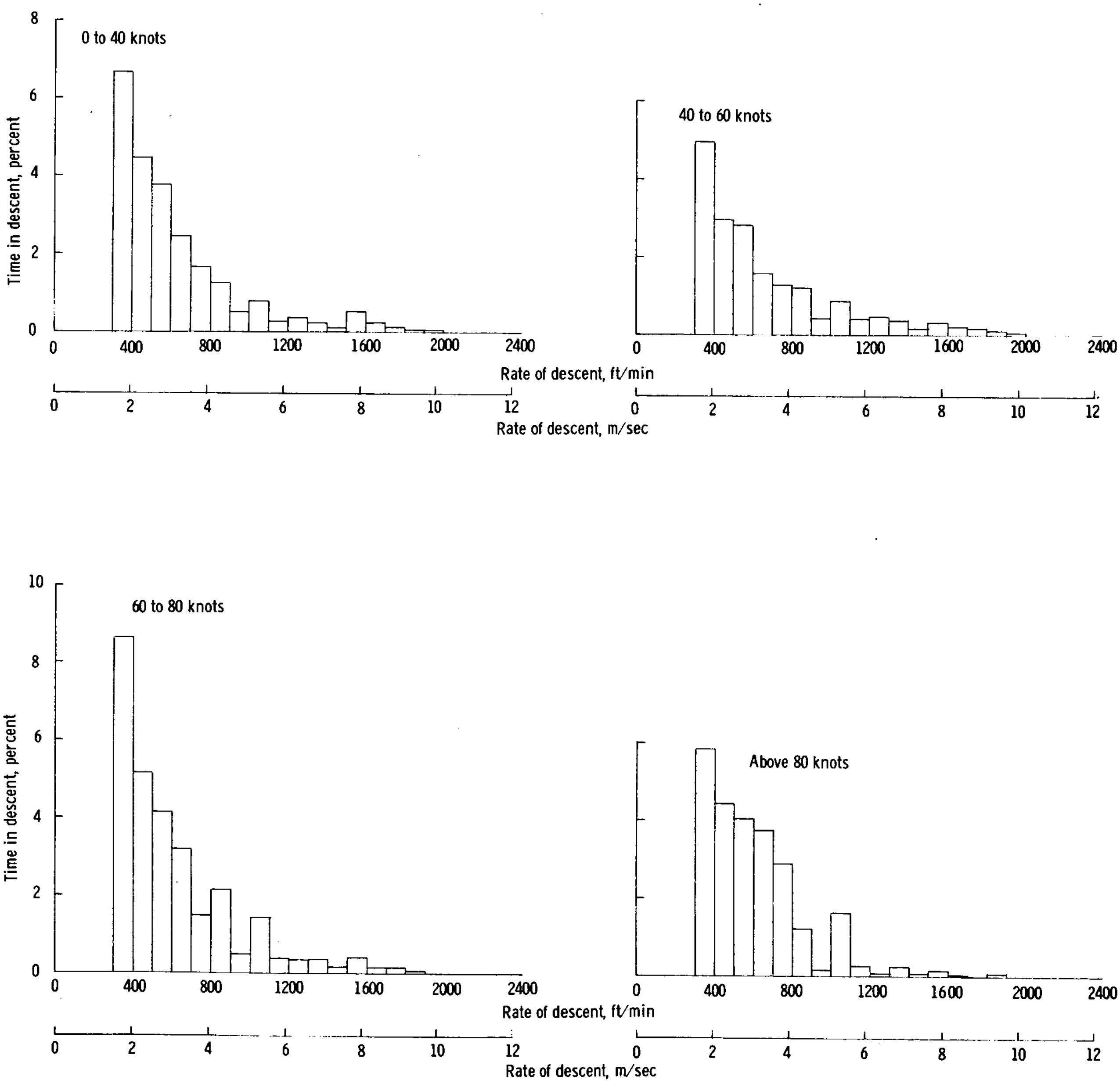
(c) Light helicopter C.

Figure 3.- Continued.



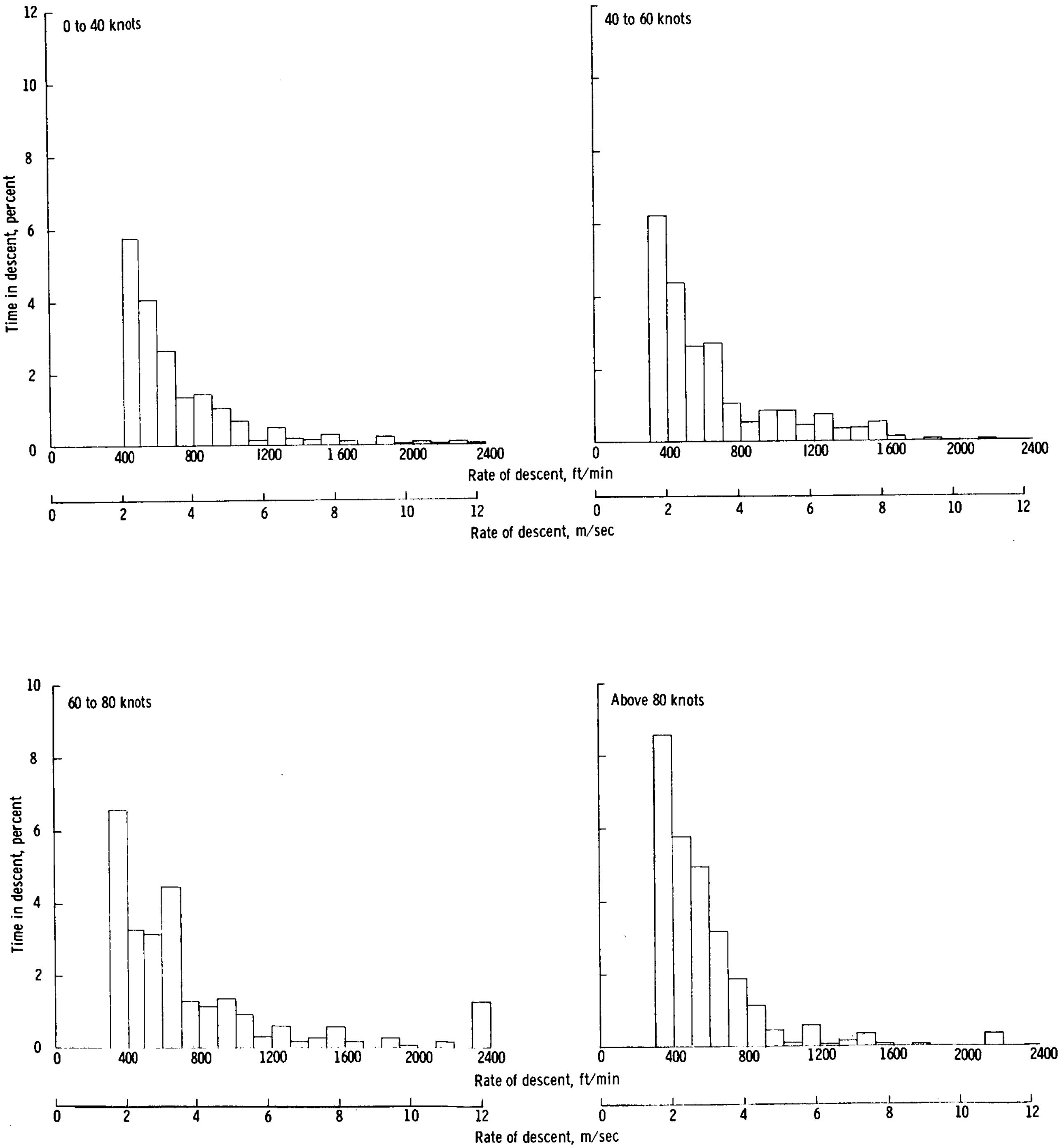
(d) Load lifters.

Figure 3.- Concluded.



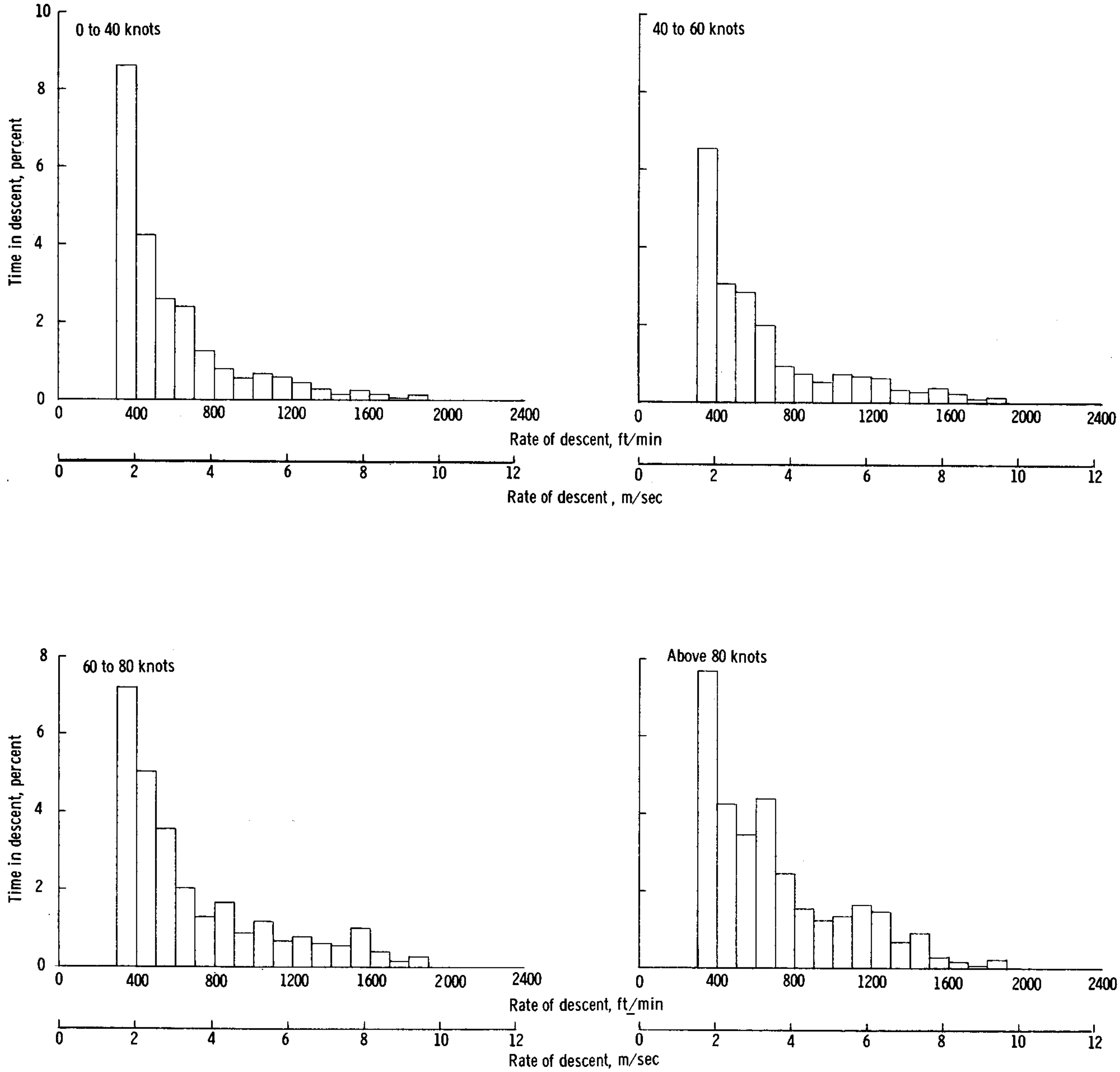
(a) Light helicopter A.

Figure 4.- Operating rates of descent within each speed bracket for each vehicle.



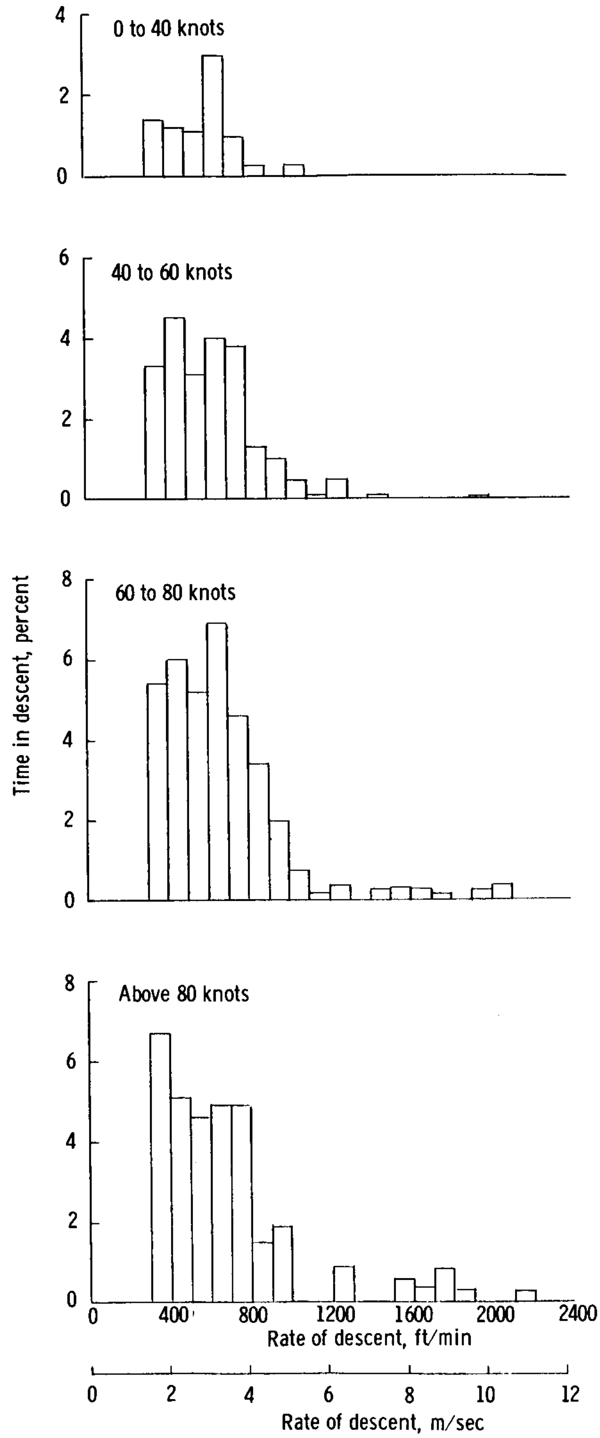
(b) Light helicopter B.

Figure 4.- Continued.



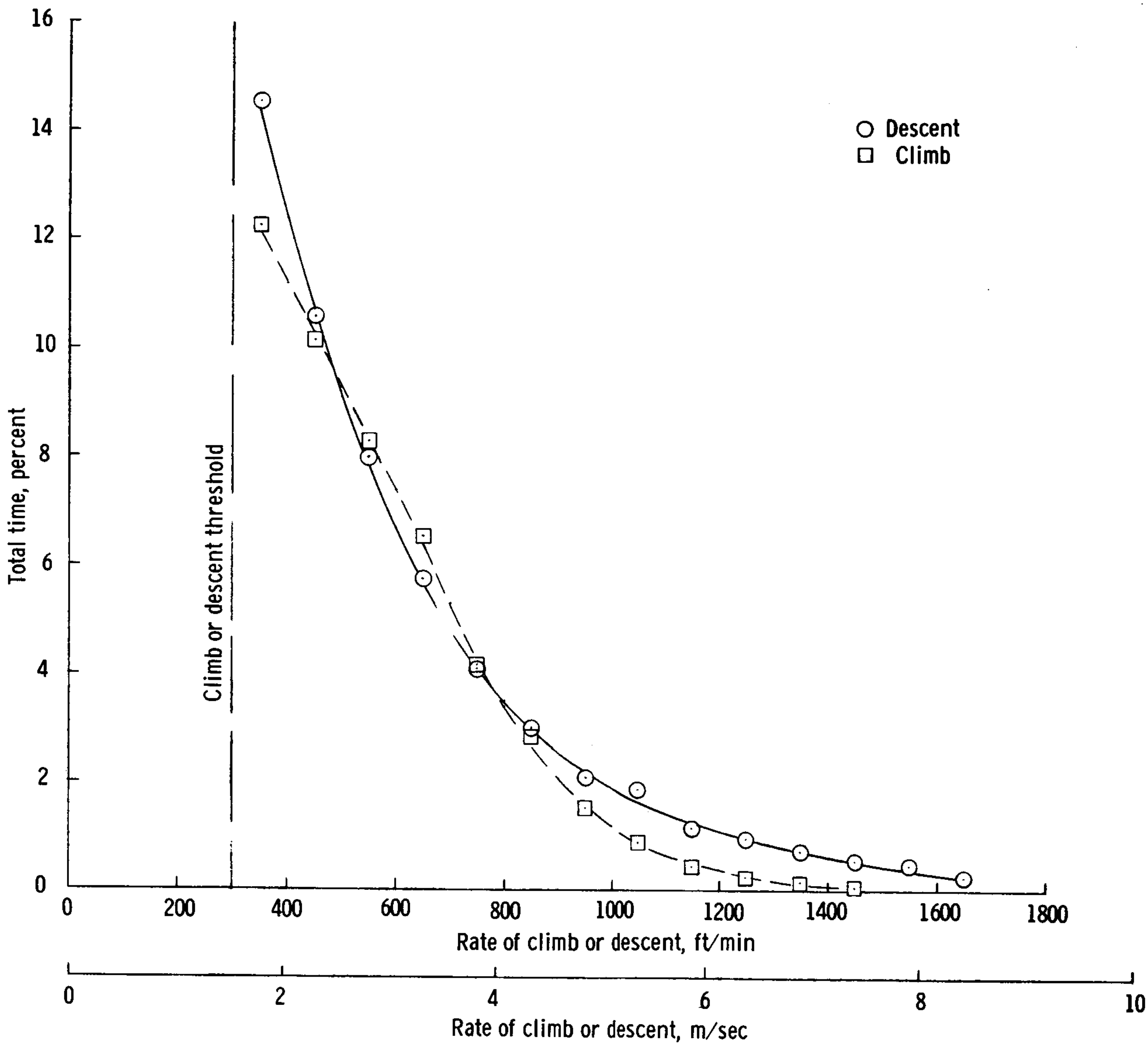
(c) Light helicopter C.

Figure 4.- Continued.



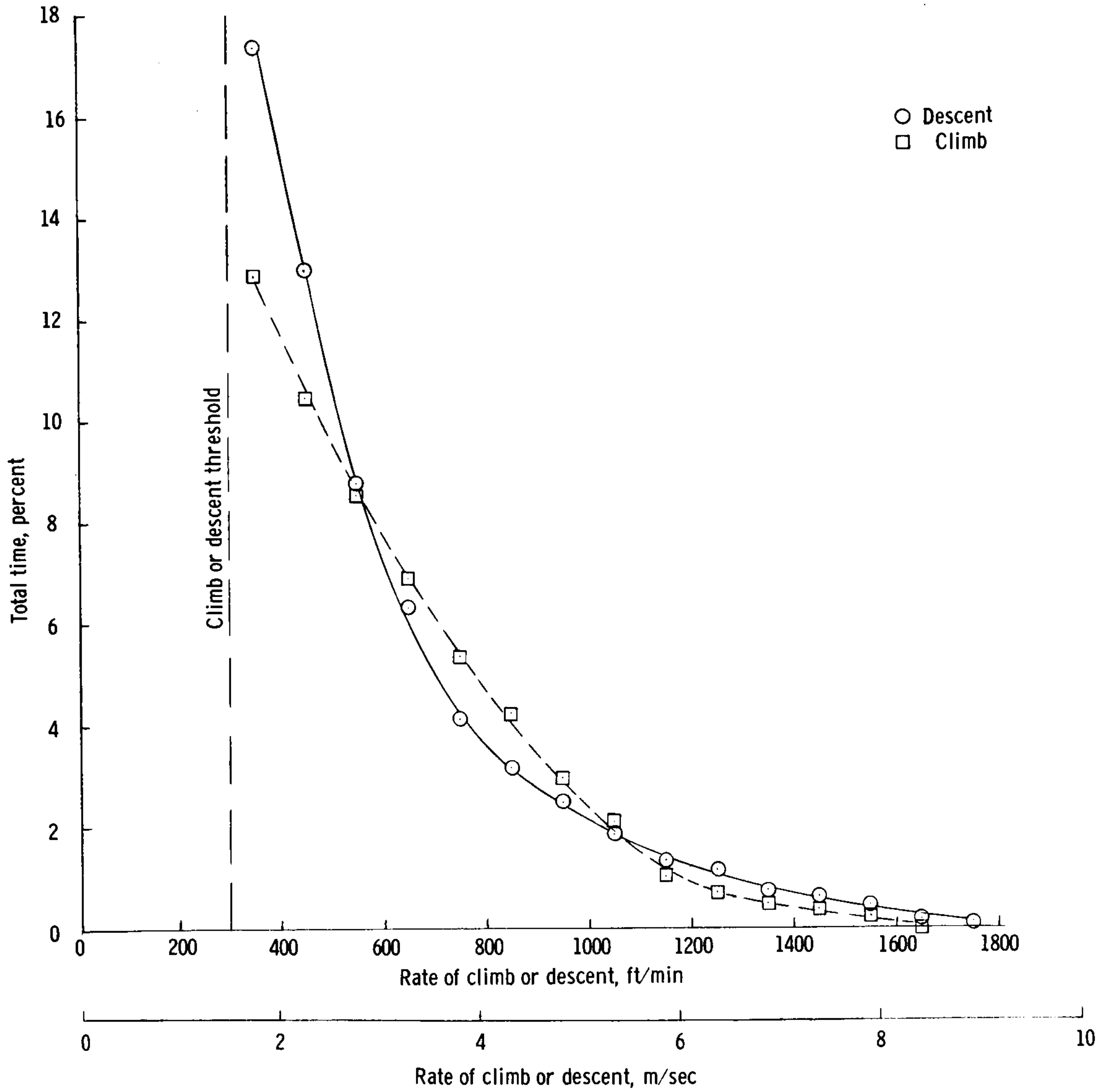
(d) Load lifters.

Figure 4.- Concluded.



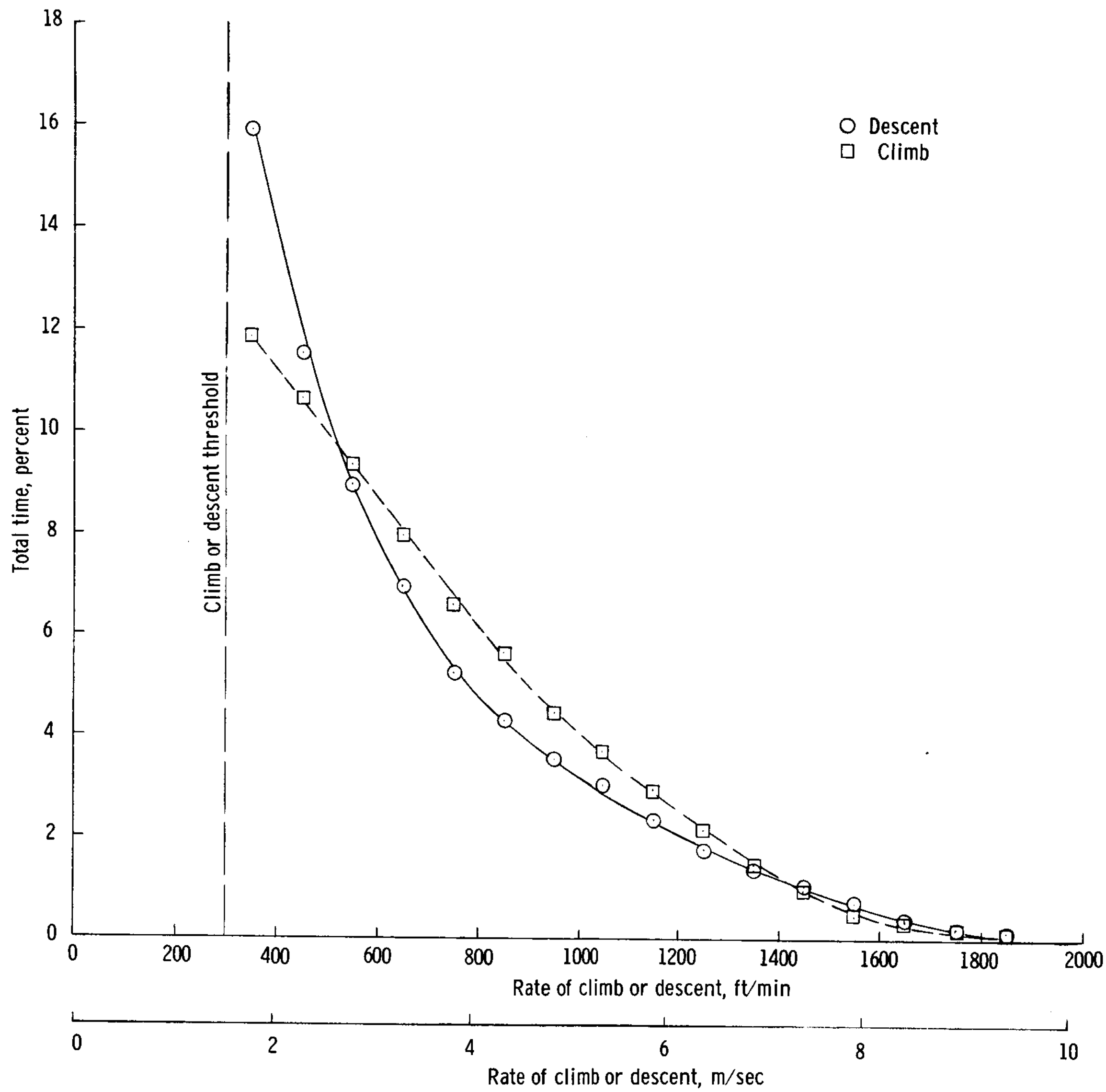
(a) Percent of time rates exceeded by light helicopter A.

Figure 5.- Summary of the percentage of total flight time required to exceed a given rate of climb or descent.



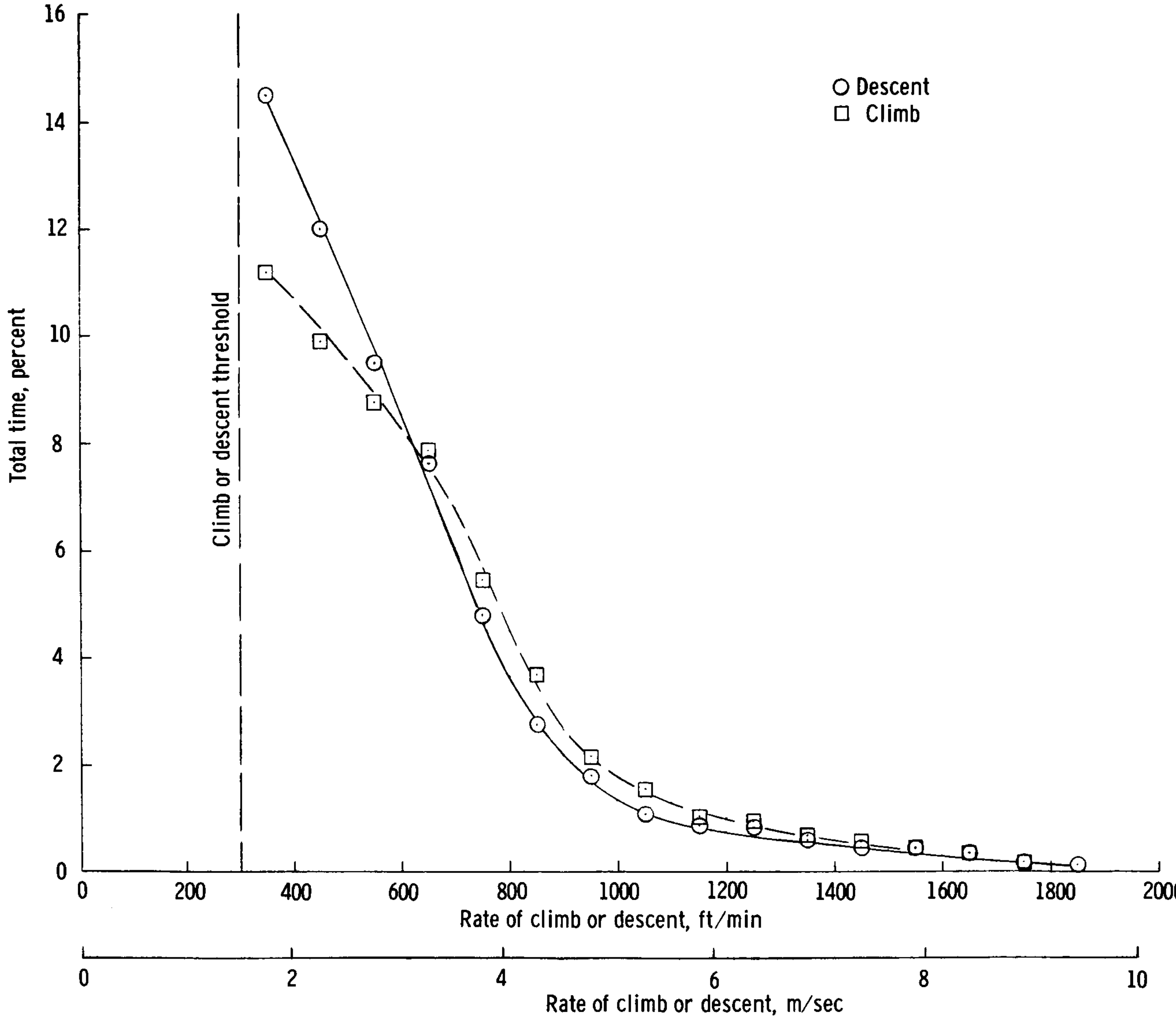
(b) Percent of time rates exceeded by light helicopter B.

Figure 5.- Continued.



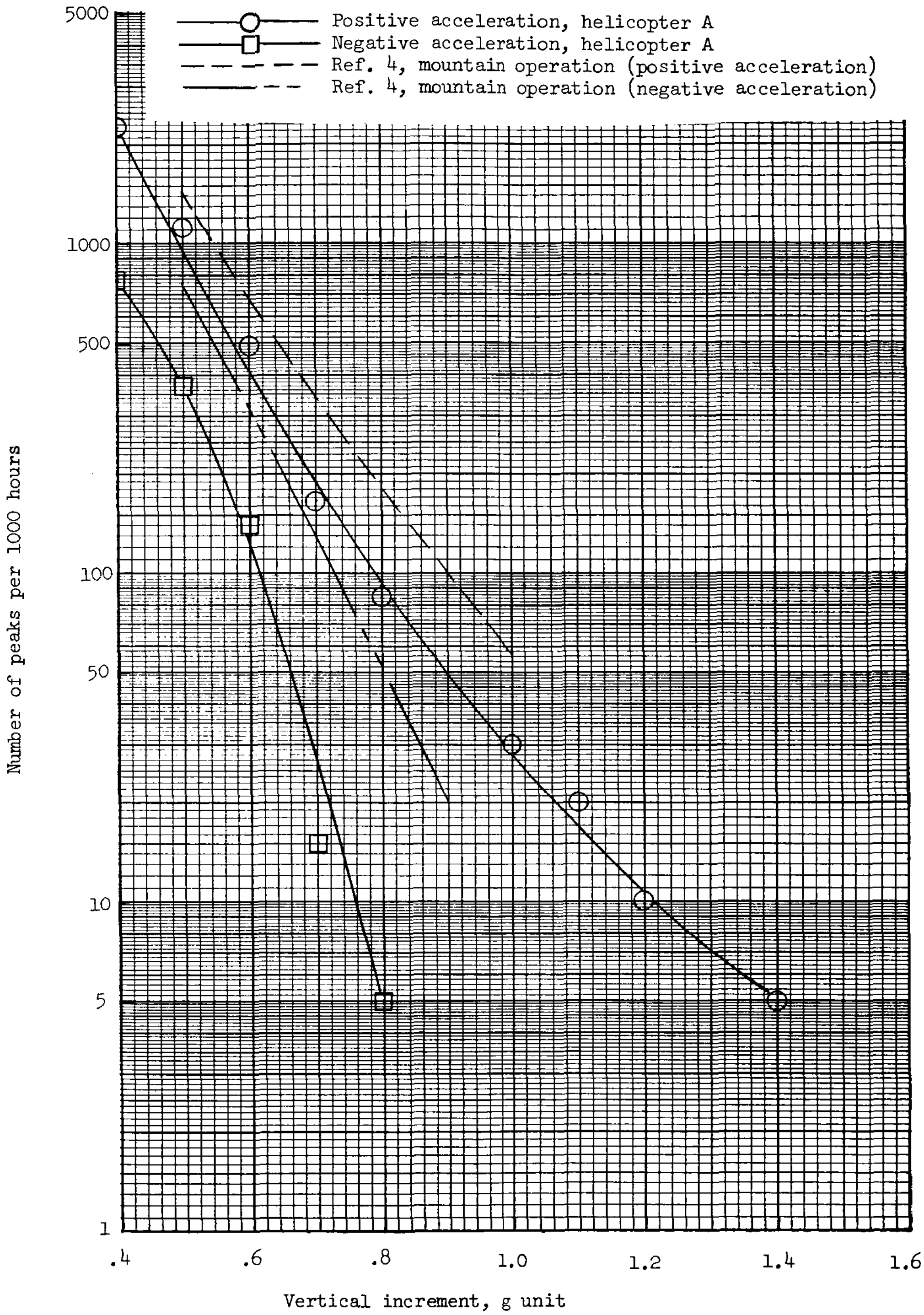
(c) Percent of time rates exceeded by light helicopter C.

Figure 5.- Continued.



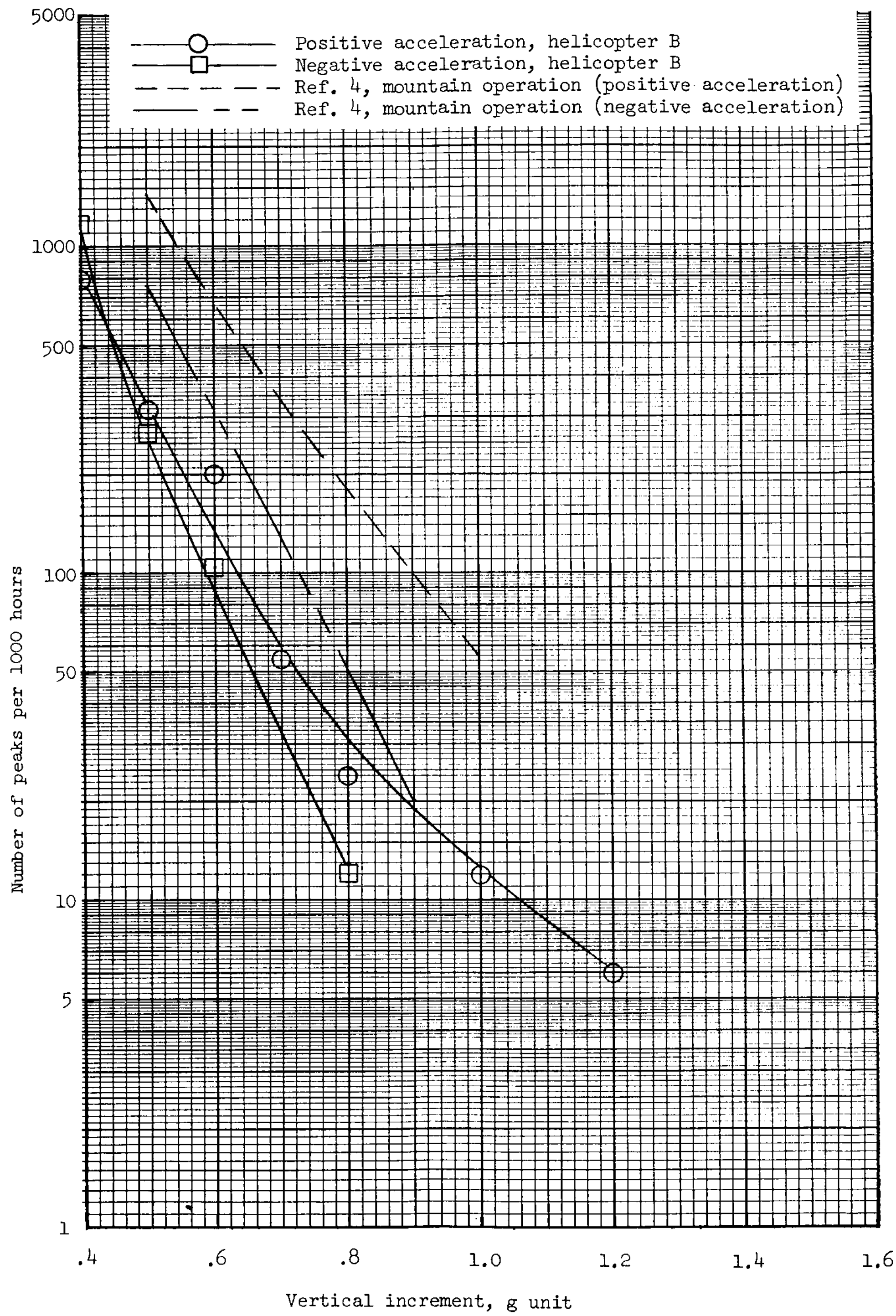
(d) Percent of time rates exceeded by the load lifters.

Figure 5.- Concluded.



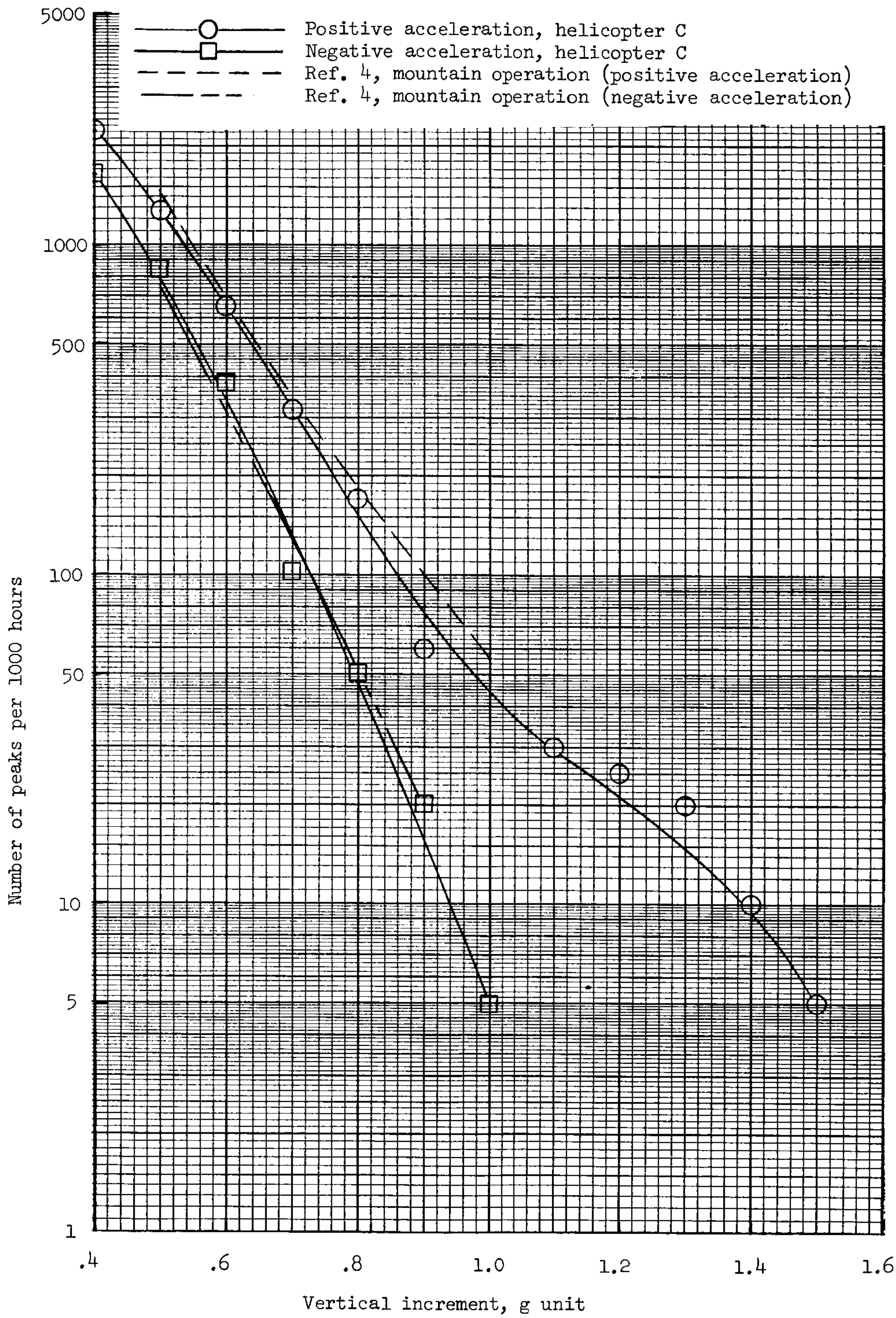
(a) Light helicopter A.

Figure 6.- Frequency of occurrence, per 1000 flight hours, of normal-acceleration increments.



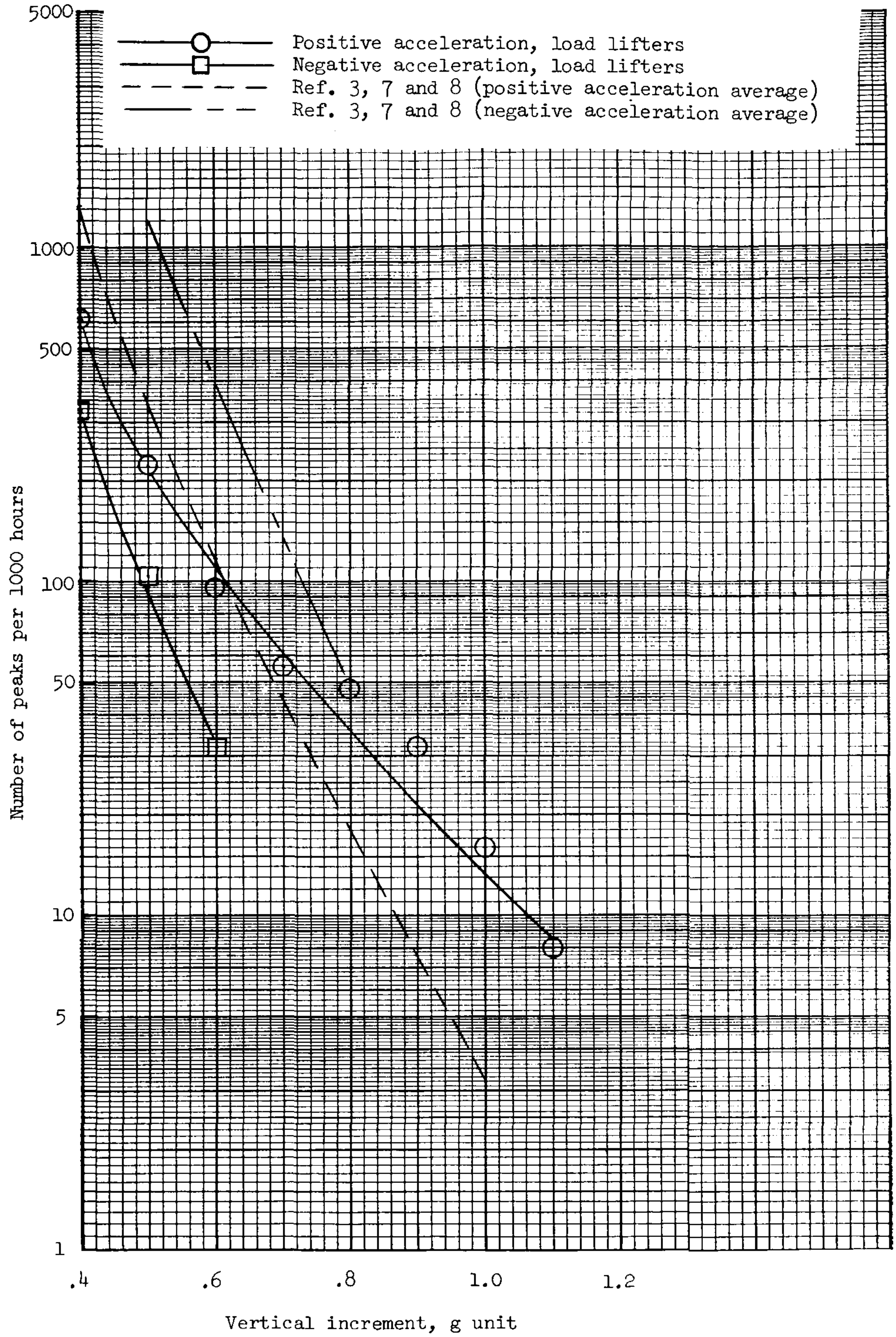
(b) Light helicopter B.

Figure 6.- Continued.



(c) Light helicopter C.

Figure 6.- Continued.



(d) Load lifters.

Figure 6.- Concluded.

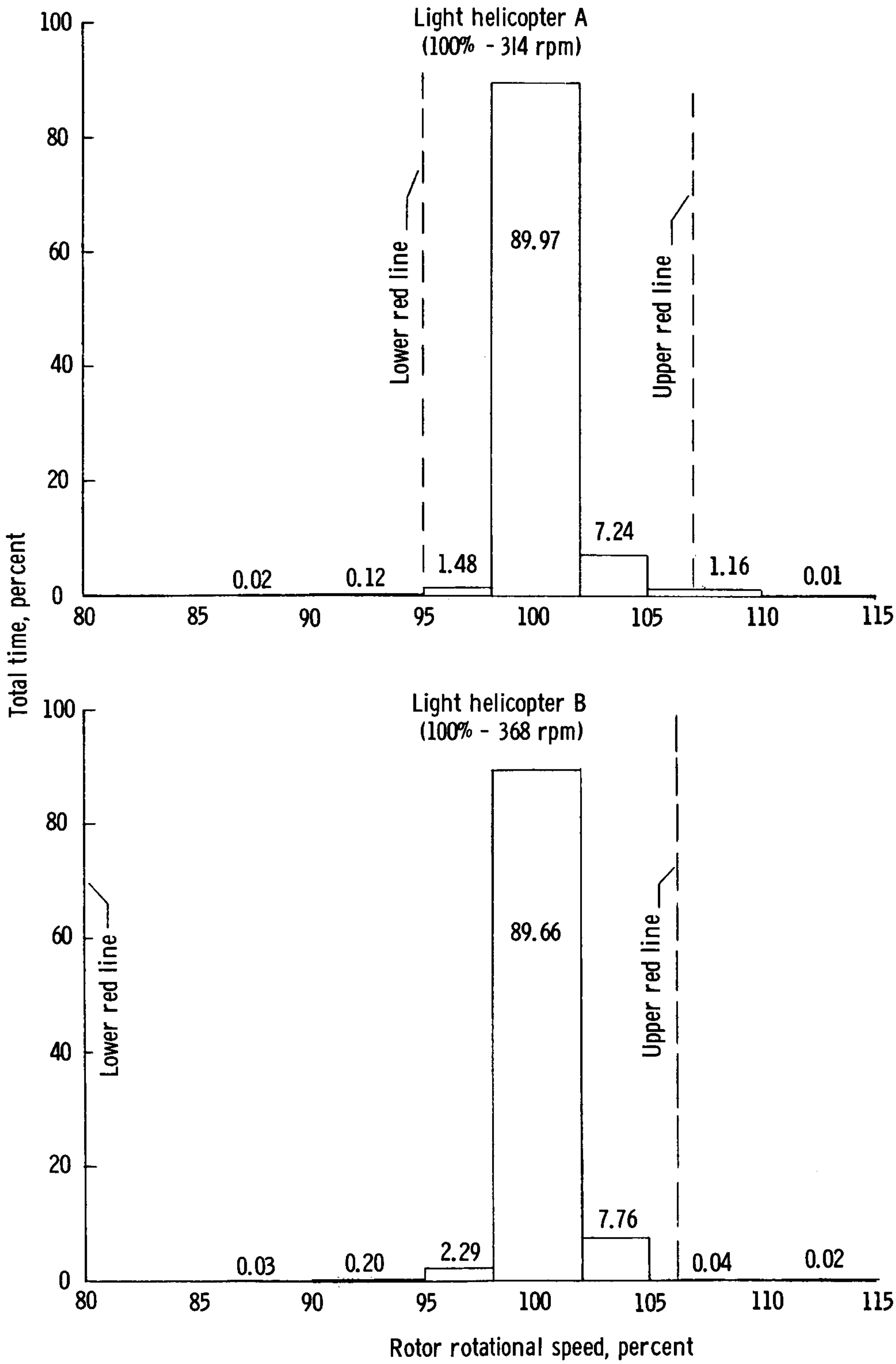


Figure 7.- Operating rotor rotational speeds experienced by each of the vehicles.

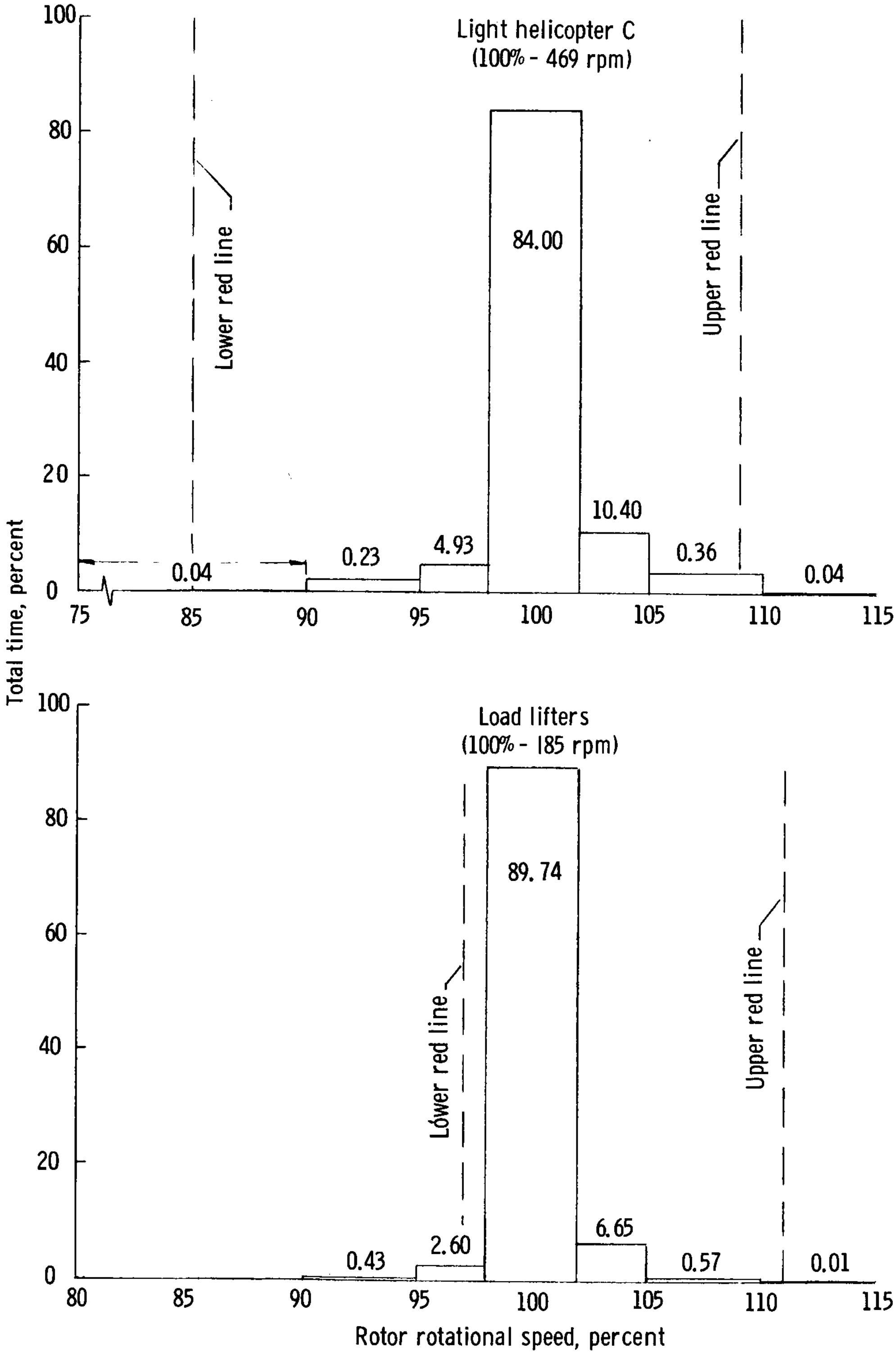


Figure 7.- Concluded.

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